DOE/PC/92521--T241

TECHNICAL REPORT
March 1 through May 31, 1995

Project Title: **MANUFACTURE OF AMMONIUM SULFATE FERTILIZER FROM FGD-GYPSUM**

DOE Cooperative Agreement Number:	DE-FC22-92PC92521 (Year 3)
ICCI Project Number:	94-1/3.1B-3M
Principal Investigator:	M.-I.M. Chou, Illinois State Geological Survey (ISGS)
Other Investigators:	M. Rostam-Abadi, J.M. Lytle, J.A. Bruinius, and Y.C. Li (ISGS); R. Hoeft, University of Illinois, Urbana-Champaign (UIUC); S. Dewey, AlliedSignal-Chemicals; F. Achorn, Southeast Marketing Chem. Process Inc. (SE-ME)
Project Manager:	D. D. Banerjee, ICCI

ABSTRACT

The overall goal of this project is to assess the technical and economic feasibility for producing fertilizer-grade ammonium sulfate from gypsum produced as part of limestone flue gas desulfurization (FGD) processes. This is the first year of a two-year program with cooperative effort among the ISGS, the UIUC, AlliedSignal, SE-ME, Henry Fertilizer, Illinois Power Co. (IP), and Central Illinois Public Services (CIPS). In the previous quarter, chemistry of the process and process conditions have been reviewed and the information was used to set up a reactor system. The system was used to conduct several laboratory tests. FGD-gypsum produced at the Abbott power plant in Champaign, IL was used as a raw material. The scrubber, a Chiyoda Thoroughbred 121 FGD, produced a filter cake product contains 98.36% gypsum ($CaSO_4 \cdot 2H_2O$), and less than 0.01% calcium sulfite ($CaSO_3$). Conversion of FGD-gypsum to ammonium sulfate were tested at temperatures between 60 to 70°C for a duration of five to six hours. A yield of up to 82% and a purity of up to 95% for the ammonium sulfate production was achieved.

In this quarter, more bench-scale experiments including a mass balance analysis were conducted. Based on the weight of the ammonium sulfate produced and its theoretical yield from a total conversion of calcium sulfate feed, a yield of up to 83% and a purity of up to 99% for the ammonium sulfate production was achieved. Also, a more complete literature survey was conducted and a preliminary process flow sheet was developed. Using the flow sheet and engineering data, the economics of the process are being estimated. The cost estimates results will be reported in the next quarter. Also, any beneficial process variation to be considered and process limitations that need further research will be identified.

EXECUTIVE SUMMARY

Progress made under the United States Department of Energy's Clean Coal Technology program and the 1990 amendments to the Clean Air Act that mandate a 2-stage 10-million ton reduction in sulfur dioxide emissions in the United States have definitely promoted the use of FGD technologies. In addition to capital costs for equipment and operating expenses, plants burning high sulfur coal and using FGD technologies must also bear increasingly expensive landfill disposal costs for the solid waste produced. The FGD technologies would be less of a financial burden if successful commercial uses were developed for the gypsum-rich by-products of wet limestone scrubbing. Conversion of FGD-gypsum to a marketable product could be a deciding factor in the continued use of high-sulfur Illinois coals by electric utilities.

The conversion of FGD-gypsum to calcium carbonate and ammonium sulfate by reacting it with CO_2 and ammonia or by reacting it with ammonium carbonate is being studied in this program. A variation of this process could provide electric utilities a means to convert the CO_2 and SO_2 in their flue gas to useful commercial products. The fertilizer industry would also be provided with a large source of ammonium sulfate to supply sulfur nutrient in NPK fertilizer blends. The need of from five to 10 million tons annually of new ammonium sulfate production for the fertilizer market is anticipated.

Goals and Objectives

The overall goal of this project is to assess the technical and economic feasibility for producing commercial-grade ammonium sulfate fertilizer from FGD-gypsum. The project focuses on developing process engineering data, costs for the production of the fertilizer, and market demand for the product in the agricultural community. If successful, the results of this project could provide a solution, from both environmental and economic standpoints, to the problem of disposing of large quantities of by-products from FGD processes.

Specific objectives of this study are

I. Assess current knowledge on the chemistry, process schemes, and production costs of ammonium sulfate from gypsum.

II. Obtain samples of FGD-gypsum from two Illinois power plants for the work proposed in the project.

III. Obtain engineering data required for process scale-up and the technical and economic feasibility studies.

IV. Determine the influence of coal-derived impurities in the gypsum upon process conditions and the quality of the ammonium sulfate produced.

V. Evaluate the impact of continued use of FGD-gypsum-derived ammonium sulfate on soil chemical properties.

VI. Establish a process flow sheet for the production of ammonium sulfate from FGD gypsum and evaluate the production costs and the market potential for the product.

This project is a cooperative effort among the ISGS, UIUC, AlliedSignal, SE-ME, Henry Fertilizer, Illinois Power Co. (IP), and Central Illinois Public Services (CIPS). A literature review and bench-scale experiments will be conducted by the ISGS and SE-ME to obtain process engineering data for the manufacture of ammonium sulfate from FGD-gypsum and to help evaluate technical and economic feasibility of the process. Controlled greenhouse experiments will be conducted at UIUC to evaluate the chemical impact of coal-derived impurities in ammonium sulfate produced from FGD-gypsum. A process flow sheet and market demand for the products will be established. An engineering team at IP will provide an independent review of the economics of the process. AlliedSignal will be involved in testing the quality of the ammonium sulfate and is interested in an agreement to market the finished product. CIPS will provide technical assistance and samples of FGD-gypsum for the project.

In the previous quarter, chemistry of the process and process conditions were reviewed and the information was used to set up a reactor system. FGD-gypsum produced at the Abbott power plant in Champaign, IL was used as a raw material. Conversion of FGD-gypsum to ammonium sulfate were tested at temperatures between 60 to 70°C for a duration of five to six hours. A yield of up to 82% and a purity of up to 95% for the ammonium sulfate production was achieved.

In this quarter, more bench-scale experiments including a mass balance analysis were conducted. A preliminary mass balance calculation for calcium and sulfur show a recovery of 98% for calcium in calcium carbonate and a recovery of 81% for sulfur in ammonium sulfate. Based on the weight of the ammonium sulfate produced and its theoretical yield from a total conversion of calcium sulfate feed, a yield of up to 83% and a purity of up to 99% for the ammonium sulfate production was achieved. The laboratory tests results indicate that high quality ammonium sulfate can be produced from the FGD-gypsum obtained from the Abbott power plant. Based on historical use of the Merseburg process and studies conducted by the Tennessee Valley Authority, a preliminary flow diagram for the production of ammonium sulfate fertilizer from FGD-gypsum was developed. The major equipment for the process includes an absorption tower, the gypsum converter, a concentrator and two crystalizers, and various equipment for drying and solid handling. If the product of a specified size can not be produced in the crystallizer the small crystals will have to be increased in size by pressing the material between rolls in a compaction plant. The capital costs of the equipment and production cost of the process with and without compaction cost are being estimated. The results will be reported in the next quarter. Also, any beneficial process variation to be considered and process limitations that need further research will be identified.

GOALS AND OBJECTIVES

The overall goal of this project is to assess the technical and economic feasibility for producing commercial-grade ammonium sulfate fertilizer from FGD-gypsum. This project focuses on providing process engineering data, estimating costs for the fertilizer production, and evaluating marketability of the product in the agricultural community.

Specific objectives of this study are

I. Assess current knowledge on the chemistry, process schemes, and production costs of ammonium sulfate from gypsum.

II. Obtain samples of FGD-gypsum from two Illinois power plants for the work proposed in the project.

III. Obtain engineering data required for process scale-up and the technical and economic feasibility studies.

IV. Determine the influence of the properties of the gypsum and process conditions on the quality of the ammonium sulfate produced.

V. Evaluate the impact of continued use of ammonium sulfate on soil chemical properties.

VI. Establish a process flow sheet for the production of ammonium sulfate from FGD gypsum and evaluate the production costs and the market potential for the product.

INTRODUCTION AND BACKGROUND

Wet flue gas desulfurization (FGD) processes, that use limestone to scrub SO_2 from flue gas are advanced pollution control technologies that will remain preferred choices for Phase-II compliance because of their advanced level of commercial development and demonstrated operational experience. A FGD system installed on a 500-MW plant burning 3.5% sulfur coal, with a desulfurization efficiency of 95%, can generate about 47 tons of gypsum per hour if the conditions for oxidation of sulfite to sulfate are met. From an environmental and economic standpoint, it is desirable to use this by-product as a feed material to produce a salable product. The goal of this project is to assess the technical and economic feasibility for producing commercial-grade ammonium sulfate fertilizer from this gypsum.

Four major industries have agreed to work with ISGS on this project. AlliedSignal (Hopewell, VA), one of the largest producers of ammonium sulfate in the United States, is interested in developing a process to convert FGD-gypsum to granular ammonium sulfate. AlliedSignal will evaluate samples of the ammonium sulfate produced and consider making an agreement to market the finished product. Illinois Power (IP) and Central Illinois Public Services (CIPS), which have long advocated the development of markets for coal by-products, endorse the evaluation of the concepts proposed in this research project. IP will provide an independent review of the economics of the process and CIPS will provide technical assistance and samples of gypsum-sludge for testing. Henry Fertilizer (Henry, Illinois), will provide technical assistance on the project and will allow the use of their commercial facility if the project advances to a scale-up stage.

Regulations to reduce sulfur dioxide emissions in the year 1995 (phase I: 2.5 lbs $SO_2/10^6$ Btu) and the year of 2000 (phase II: 1.2 lbs $SO_2/10^6$ Btu) are mandated by the 1990 Clean Air Act Amendments. Millions of tons of high-quality gypsum may be produced in this decade. The total amount depends partly on additional installation of FGD systems. The amount of FGD-gypsum by-product could exceed the current demand of the FGD-gypsum industry. The anticipated problems for utilities are increased disposal costs plus limited landfill space. Successful commercial utilization of FGD by-products would improve the FGD economics.

The degree to which FGD-gypsum is commercially used depends on its quality. Currently, high-quality FGD-gypsum with purity greater than 94% is used mainly to manufacture construction materials, i.e. stucco and gypsum-plaster, gypsum wall boards, and cement. Lower quality FGD gypsum is less desirable and, unless a market materializes to use it, a significant percentage of this by-product will require disposal as a solid waste. Several methods for the use of low quality FGD-gypsum have been proposed and, in many cases, demonstrated. Stabilized FGD material can be used as a liner for a landfill. Some FGD materials are processed to a fixed stabilisate and disposed in abandoned surface coal mines. An alternate approach to utilize both high and low quality FGD-gypsum is to produce ammonium sulfate fertilizer.

Ammonium sulfate is a valuable nutrient source for both nitrogen and sulfur for growing plants. There is a growing demand for sulfur as a plant nutrient in the sulfate form because of diminished deposition of sulfur compounds from flue gas emissions and more sulfur is taken up by plants produced in high yields. Also, the trend of using high nitrogen content fertilizers has pressed incidental sulfur compounds out of traditional fertilizer. The current market for ammonium sulfate in the United States is about two million tons per year. It is anticipated that 5 to 10 million tons of new ammonium sulfate production may be required for fertilizer markets annually to make up for the loss of sulfur deposition from the increase restriction on acid-rain. The fertilizer industry appears ready to accept an added source of fertilizer grade ammonium sulfate to supply sulfur in NPK fertilizer blends. Currently, the wholesale price for granular ammonium sulfate ranges from $75 to $130 per ton. At these price levels, converting some of the FGD-gypsum to ammonium sulfate becomes an attractive solution an Illinois disposal problem and could improve the economics of FGD systems in the state.

An ammonia-based FGD process, which produces ammonium sulfate as by-product, has been developed by General Electric (GE) and tested on a pilot-scale at the Great Plains Synfuel Plant in Beulah, ND. An economic study conducted by GE shows that for coals greater than 3% sulfur, this FGD process is favored over the forced oxidation process when the selling price of ammonium sulfate is greater than $40/ton. The annual levelized cost was shown to decrease with increasing sulfur content of the coal when the ammonium sulfate price is greater than $70/ton. There are no published reports on the economics of converting FGD-gypsum to ammonium sulfate.

EXPERIMENTAL PROCEDURES

Conversion of FGD-gypsum to ammonium sulfate and calcium carbonate - The batch, bench-scale reactor system consisted of a 1000-mL, three-neck, round-bottomed flask fitted with a mechanical stirrer, a condenser, and a thermometer. An autotransformer and heating mantle were used to control the reaction temperature. The important reaction for producing ammonium sulfate from the FGD-gypsum is the reaction between ammonium carbonate and calcium sulfate. Two sets of experiments were conducted. In the first set of experiments, the gypsum reacted with reagent-grade ammonium carbonate in aqueous medium. In the second set of experiments, ammonium carbonate, formed by the reaction of ammonia and carbon dioxide in a liquid medium reacted with suspended gypsum. The procedures for the experiments are outlined below.

FGD-gypsum was added to an ammonium carbonate solution (prepared by dissolving reagent-grade ammonium carbonate in 500 mL of distilled water) in the 1000-mL reaction flask. The temperature of the stirred mixture was raised from room temperature to the reaction temperature and maintained at that temperature for a range of pre-determined times. The solution which contained the ammonium sulfate product was separated from the solid byproduct, calcium carbonate, by vacuum filtration. The filtrate plus the rinsing, a total of about 600 mL of the liquid, was concentrated to a volume of about 150 mL in a constant temperature water bath. The residual concentrate was kept at room temperature to form ammonium sulfate crystals. The condensation and crystallization steps were repeated until no more crystal could be produced. The combined product was dried under ambient air before determining the total weight.

In the second set of experiments, ammonium carbonate was formed by the reaction of ammonia and carbon dioxide in aqueous medium, which was then allowed to react with FGD-gypsum in suspension. After removal of the calcium carbonate, the ammonium sulfate is recovered in a similar manner by filtration, evaporation and crystallization.

The ammonium sulfate produced was analyzed by melting point determination, chemical analysis and TGA analysis. The yield of the ammonium sulfate produced was obtained based on its theoretical yield from a total conversion of calcium sulfate feed. The purity of the ammonium sulfate produced was determined by chemical analysis of the nitrogen content using methods described by the Association of Official Analytical Chemists (AOAC) and American Water Works Association (AWWA) procedure, and by ASTM method C-471. The calcium carbonate by-product was dried and subjected to TGA analyses to determine its purity and composition of unreacted gypsum.

Process flow diagram - Chemistry of the process and process conditions have been previously reviewed. In this quarter, both TVA's Technical Library and the International Fertilizer Development Center (IFDC) Library were used for a more complete literature survey to obtain data on engineering design, operating parameters, and material and equipment size information. Both of these libraries are located in Muscle Shoals, AL. Also, City Water and Light, Springfield, IL was contacted for the capacity of FGD-gypsum produced.

RESULTS AND DISCUSSIONS

Bench scale testing for ammonium sulfate production - Previously, chemistry of the process and process conditions have been reviewed and the information was used to set up a reactor system and to conduct some laboratory tests. The important reaction for producing ammonium sulfate from the FGD-gypsum is the reaction between ammonium carbonate and calcium sulfate. Two sets of experiments (see experimental procedures section) were conducted. The reaction conditions, amounts of reactants, and the properties of products for the two sets of experiments are listed in Table 1. The ammonium sulfate produced was confirmed both by comparing its melting point with that of a commercial standard and by examining chemical analysis data and TGA data. Based on the weight of the ammonium sulfate produced and its theoretical yield from a total conversion of calcium sulfate feed, a yield of up to 83% and a purity of up to 99% for the ammonium sulfate production was achieved.

A mass balance calculation for calcium and sulfur was conducted on experiment run No. 5 (Table 1). The results show a recovery of 98% for calcium in calcium carbonate and a recovery of 81% for sulfur in ammonium sulfate were obtained. The TGA curve for calcium carbonate produced in one of the residues is shown in Figure 1. The graph shows a weight loss occurring between 600°C and 770°C. This is attributed to the evolution of carbon dioxide from decomposing calcium carbonate. A typical TGA curve (Figure 2) of the ammonium sulfate produced shows a total decomposition of the sample with a maximum weight loss at 418.3°C.

The results of these laboratory tests suggest that high quality ammonium sulfate can be produced from the FGD-gypsum sample obtained from the Abbott power plant.

Table 3. Reaction conditions and the results of final product and by-product analyses

Run number	Run Conditions	[1] Mole ratio	$CaCO_3$		$(NH_4)_2SO_4$		
			[2] Wt% in residue	[3]Calculated yield	[4]purity	[3]Calculated yield	[5]m.p. (°C)
1	70°C 5hr	1.56	97	ND	ND	ND	242
2	70°C 6hr	1.59	86	ND	95	82	237
3	70°C 6hr	1.33	81	81	ND	83	241

Run number	Run conditions	NH_3 mole/hr	CO_2 mole/hr	$CaCO_3$		$(NH_4)_2SO_4$		
				[2]wt% in residue	[3]calculated yield	[4]purity	[3]Calculated yield	[5]m.p. (°C)
4	60°C 4hr[6]	1.50	1.25	ND	ND	99	58	240
5	65°C 6hr[6]	1.25	1.00	94	104	95	83	241
6	70°C 6hr[6]	1.25	1.00	ND	ND	90	76	237

[1]The mole ratio of $(NH_4)_2CO_3$ to $CaSO_4 \cdot 2H_2O$
[2]Wt % $CaCO_3$ in residue by TGA
[3]Based on theoretical yield from FGD-gypsum feed
[4]Wet chemical analysis by ASTM C-471 and AWWA procedures
[5]Melting point for the standard is 240°C
[6]1.95 mole of gypsum used.

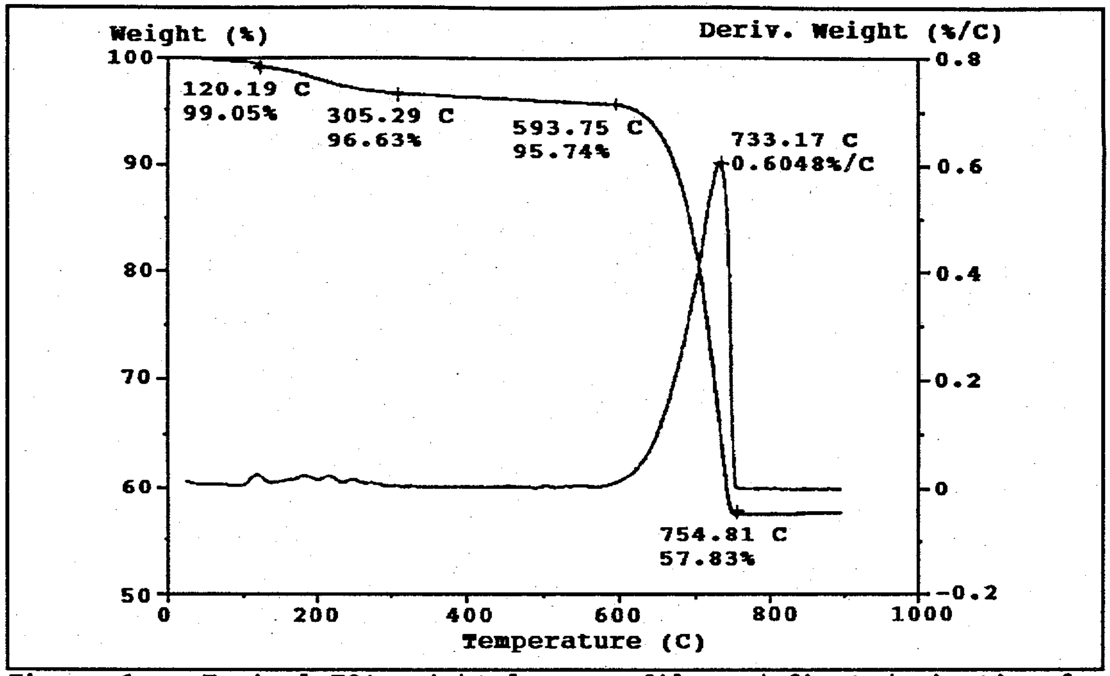

Figure 1: Typical TGA weight loss profile and first derivative for solid by-product ($CaCO_3$) from the ammonium sulfate production.

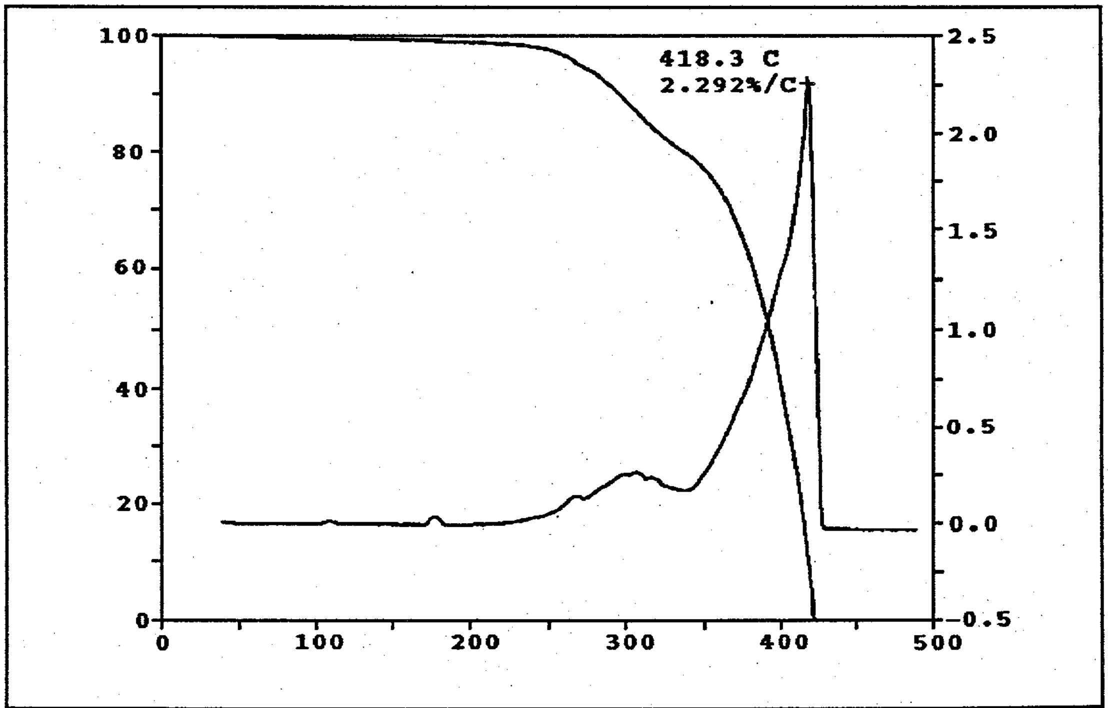

Figure 2: Typical TGA weight loss profile and first derivative of ammonium sulfate produced.

Process description and process flow sheet - In this quarter, more complete literature survey was conducted to identify engineering parameters and to establish process flow sheet. The flow sheet is proposed, as shown in Figure 3. It includes an absorption tower, the gypsum converter, a concentrator and two crystalizers, and various equipment for drying and solid handling. The process is described as follows.

The process is similar to the one used in Europe and India in the 1960's to produce large quantities of ammonium sulfate from natural gypsum (ACS, 1964). Some modification have been made because of more recent studies. The largest change is the gypsum conversion reactor which is based on the TVA pilot plant tests (Meline et.al, 1971). Figure 3 shows the proposed Flow Diagram to convert gypsum to ammonium sulfate fertilizer and calcium carbonate. The idea is to build the plant near a utility or a lime producing plant which can supply the carbon dioxide (CO_2).

Ammonium carbonate, the other major reactant, is formed by reacting carbon dioxide and ammonia in aqueous solution. This is completed by absorbing the carbon dioxide and ammonia in an absorption tower.

The ammonium carbonate solution is then mixed with gypsum ($CaSO_4 \cdot 2H_2O$) and delivered to a gypsum conversion unit where the mixture is converted to ammonium sulfate solution and calcium carbonate by the following reaction:

$$(NH_4)_2CO_3 + CaSO_4 \cdot 2H_2O \rightarrow (NH_4)_2SO_4 + CaCO_3 + H_2O$$

This converter is designed similar to a phosphoric acid clarifier that is used by the phosphate industry. The overflow from the gypsum converter contain essentially all of the $(NH_4)_2SO_4$ produced in the process.

The solution from the converter is 35% ammonium sulfate and must be concentrated so the $(NH_4)_2SO_4$ crystals will form in the evaporator crystallizer. The solution will be concentrated from 35 to about 42 to 45% in a standard Swension vacuum type concentrator with forced recirculation.

The crystallizer should be designed so that crystals will be formed under controlled conditions. The ammonium sulfate solution should be supersaturated within a metastable field during the process of crystallization. To maintain this condition, the super saturated solution must be exposed efficiently to a large quantity of crystals which will bring the solution back to the saturation point before the solution is again supersaturated. These condition are necessary so that the crystal size will be large enough for sale as a granular fertilizer (particle size 1.2 to 3.3 millimeters with average 2.4 millimeters). It is believed a vacuum crystallizer that is equipped with a heat exchanger (evaporator-crystallizer) is the most desirable type crystallizer. Some of the major problems with the formation of suitably sized crystals are:

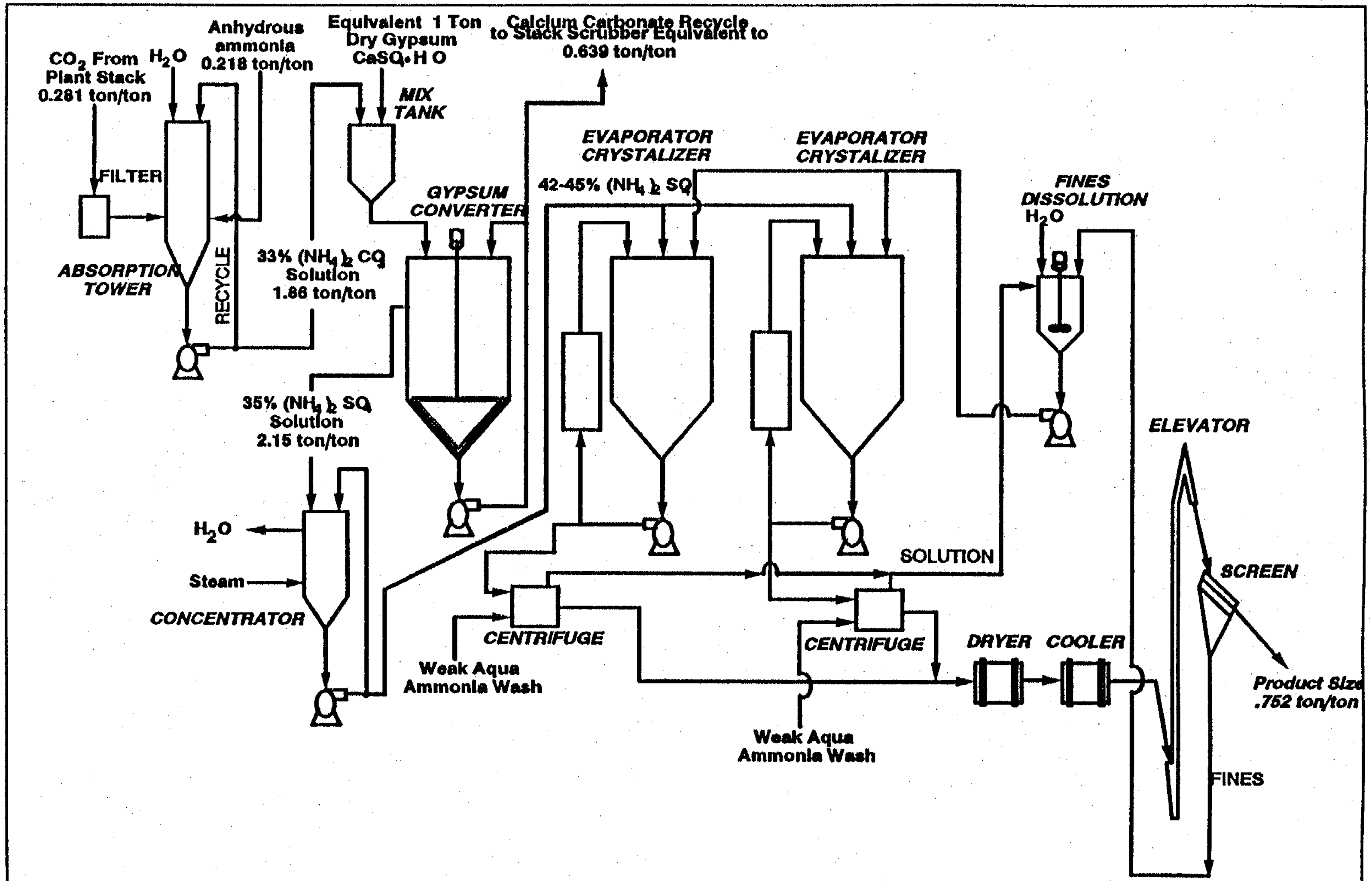

Figure 3: A Flow diagram of gypsum conversion to ammonium sulfate fertilizer and calcium carbonate.

1. A large crystallizer is required so that there will be several hours of retention time in the crystallizer.

2. Sometimes impurities such as calcium carbonate interferes with crystallization and small crystals must be produced.

Because of these reasons two medium size crystallizer were selected for the cost estimates and economic analysis.

Slurry from the crystallizer is centrifuged and washed with weak aqua ammonia. The solution from the centrifuge is used to dissolve fines from screening the product. The $(NH_4)_2SO_4$ crystals are first dried then cooled in rotary type equipment. These crystals need to be of sufficient particle size so that there will not be excessive dust losses during drying. The flow of air will first pass counter-currently through the cooler, then through a cyclone dust collector and then to the combustion chamber of the dryer thus serving as secondary air for the dryer. Exhaust gas from the dryer then passes through cyclone dust collectors and then to a bag type filter. Fines from the cyclone dust collectors, the bag filters and screens are directed to the dissolution tank where they are dissolved and returned to the crystallizer.

Material from the cooler is screened on three double deck vibrating screens. Oversize from the screens is also directed to the dissolution tank. Product size is delivered to bulk storage.

The amount of gypsum actually generated in an electric utility plant was obtained from the City Water and Light Utility of Springfield, IL. This company uses a limestone scrubbing process to remove sulfur dioxides in their exhaust gases. The resulting waste generated is calcium sulfate ($CaSO_4{\cdot}2H_2O$) or perhaps better known as gypsum. They offered the following information:

- Coal consumed per kilowatt 0.96 pounds per kwh

- Percent sulfur in coal equals about 3%

- 85 pounds of gypsum are generated per mega-watt

Based on this information the following assumptions were made:

1. 550 MkW/hr generating plant

2. 85 pounds gypsum produced per MkW/hr. This is equivalent to 561 tons of gypsum per day or 200,000 tons per year (357 operating days).

3. 0.752 tons of ammonium sulfate per ton of gypsum (98% recovery,

Figure 3) (2). This is equivalent to 422 tons per day or 150,000 tons per year (97.7% operating time).

4. Require 0.22 tons ammonia per ton of gypsum (10% excess ammonia, Figure 3) (Bennett; Hillenbrenner, 1995). This is equivalent to 123.4 tons/day or 0.292 tons NH_3 per ton $(NH_4)_2SO_4$.

5. Assume all $CaCO_3$ formed in the process will be recycled to scrubber the amount of the generating plant. The pilot plant data for the production of calcium carbonate was too high. Therefore, for estimating purposes it was assumed the theoretical value of 0.581 tons of $CaCO_3$ per ton of gypsum will be used. This is equivalent to 325.9 tons per day or 0.772 tons per ton of ammonium sulfate.

The flow sheet, engineering data, assumptions, and material balance data obtained are being used to provide a rough estimate of the production cost for ammonium sulfate from FGD-gypsum. If a suitably sized product can not be produced in the crystallizer the small crystals will have to be increased in size by pressing the material between rolls in a compaction plant. A cost estimate will be reported in the next quarter. Also, any beneficial process variation to be considered and process limitations that need further research will be identified.

SUMMARY AND CONCLUSION

The results from the additional laboratory tests indicate that high quality ammonium sulfate can be produced from the FGD-gypsum sample obtained from the Abbott power plant. A mass balance calculation for calcium and sulfur show a recovery of 98% for calcium in calcium carbonate and a recovery of 81% for sulfur in ammonium sulfate. More complete literature survey was completed to identify engineering parameters and process assumptions. A process flow sheet was proposed which includes an absorption tower, the gypsum converter, a concentrator and two crystalizers, and various equipment for drying and solid handling. Using the flow sheet and the engineering data, preliminary cost estimates are being conducted to asses the economic feasibility of producing the granular size ammonium sulfate.

REFERENCES

Benett, R.C., Product Size Distribution in Comercial Crystalizer, Chemical Engineering Progress, vol. 58, no. 9.

City Water and Light, Springfield, IL, Mr. Jeffery Hillenbrenner via telephone during March 1995.

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Meline, R.S., H.L. Faucett, C.H. Davis, and A.R. Shirley Jr., Pilot-Plant Development of the Sulfate Recycle Nitric Phosphate Process, Ind. Eng. Process Des. Develop., vol. 10, 257-264, 1971.

DISCLAIMER STATEMENT

PROJECT MANAGEMENT REPORT
March 1 through May 31, 1995

Project Title: **MANUFACTURE OF AMMONIUM SULFATE FERTILIZER FROM FGD-GYPSUM**

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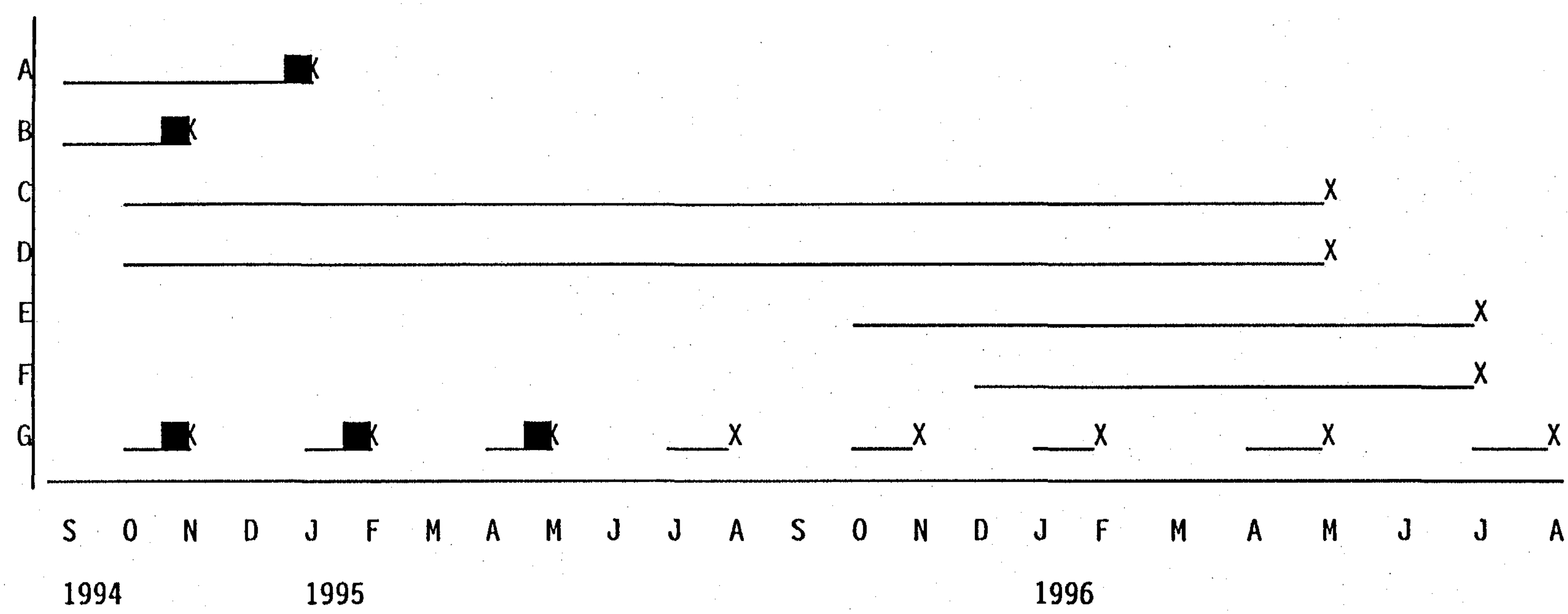
Project Manager:	D. D. Banerjee, ICCI

COMMENTS

Analyses services from various laboratories have not yet been paid. These charges are obligated but payments are made on a cost reimbursement basis after the work is completed.

SCHEDULE OF PROJECT MILESTONES



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Milestones:

A. Review literature (Task 1)
B. Acquire FGD-gypsum samples (Task 2)
C. Conduct a bench scale study (Task 3)
D. Perform characterizations (Task 4)
E. Conduct controlled green house effect study (Task 5)
F. Develop a process sheet (Task 6)
G. Submit technical and management reports (Task 7)

EXPENDITURES - EXHIBIT B

Cumulative Projected and Estimated Expenditures by Quarter

Quarter*	Types of Cost	Direct Labor	Fringe Benefits	Materials and Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Costs	Total
Sep. 1, 1994 to Nov. 30, 1995	Projected	8,920	1,984	1,500	0	0	6,137	1,854	20,395
	Estimated	3,960	880	0	0	0	1,229	607	6,676
Sep. 1, 1994 to Feb. 28, 1995	Projected	17,840	3,968	2,800	1,000	2,000	12,274	3,988	43,870
	Estimated	8,684	1,932	225	59	483	5,455	1,684	18,522
Sep. 1, 1994 to May 31, 1995	Projected	26,759	5,952	4,000	2,000	2,000	21,411	6,212	68,334
	Estimated	11,995	2,671	607	448	483	10,706	2,691	29,601
Sep. 1, 1994 to Aug. 31, 1995	Projected	33,391	7,614	5,000	2,000	2,000	27,548	7,755	85,308
	Estimated								

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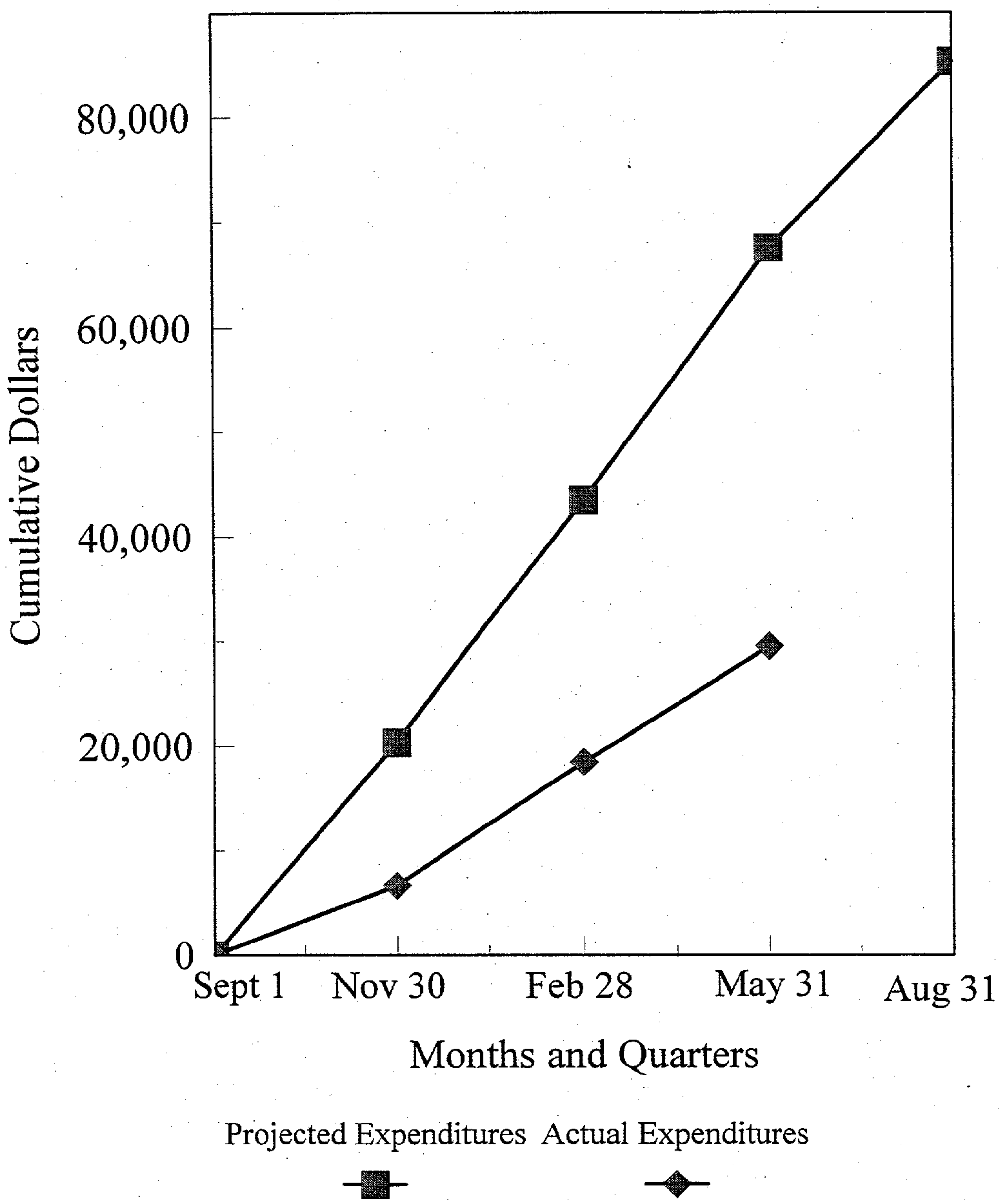
COST BY QUARTER - EXHIBIT C

MANUFACTURE OF AMMONIUM SULFATE FERTILIZER
FROM FGD-GYPSUM



Total ICCI Award <u>$ 85,308</u>